Grain Bulk Properties as Affected by Mechanical Grain Spreaders

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ABSTRACT

THE use of mechanical grain spreaders when filling bins with dry shelled corn significantly improved the uniformity of distribution of fine and broken material (chi square reduced from 3.0 to 0.3), increased the bulk density of the grain from 766 kg/m^3 to 871 kg/m^3, and increased the resistance to airflow from 122 Pa/m to 379 Pa/m at an airflow of 4.6 $m^3/min\text{-}m^2$ as compared with filling from a spout. Aeration systems designed for loosely packed grain may deliver insufficient airflow to grain in a bin filled with a mechanical grain spreader.

When a storage bin or other container is filled with a stream of granular material containing a range of particle sizes, the fine material (f.m.) concentrates in an area under the filling point. An article and a film (Van Denburg and Bauer 1964, ca. 1964) vividly demonstrate the segregation that takes place and the resultant variation in composition that is observed during unloading.

Segregation of fine material is a source of expense and problems to grain handlers. Even though a storage bin may have been filled with grain containing 3 percent f.m. uniformly distributed, if the withdrawal point is under the fill point, the first grain removed will contain considerably higher f.m. levels than will grain that is removed later. The grade may be lowered, reducing the value of the grain, or requiring reloading of the truck or rail car to meet the required grade.

Because f.m. has a higher resistance to airflow than does a mass of whole kernels, concentrations of f.m. cause a wide variation in resistance to airflow within the bin. In a drying bin, the result is inadequate drying of the core of f.m. or overdrying the remainder of the batch. Broken kernels in concentrated areas are more susceptible to insect invasion and fungal development (Christensen and Kaufmann 1969). Shotwell et al. (1972) found aflatoxin to be concentrated in damaged kernels and f.m., but not in whole kernels. The time and cost of aerating dry grain is increased by the reduced airflow in areas of high f.m.

One approach often used to combat the storage problems created by the concentration of f.m. is the removal of the core of f.m. immediately after filling by partially emptying the bin. In a large bin this may result in 20,000 bu of unused storage space which has an annual cost of 12 cents to 14 cents per bu (Dodds 1972). Even if the bin were refilled, the extra handling of the grain would add to the cost.

Several techniques have been developed to combat the nonuniform discharge characteristics of a bin (Van Denburg and Bauer ca. 1964 and 1964; Fisher 1973). These techniques usually involve the provision of internal baffles or multiple discharge points to recombine the segregated materials. However, these techniques do not correct the storage problems which arise from segragation.

Mechanical grain spreaders are sometimes used to prevent f.m. segregation, although their primary selling point has been that they provide a level fill without hand labor. Some manufacturers refer to the drying problems caused by fine material segregation.

The objectives of this study were: (a) to measure the effectiveness of mechanical grain spreaders in producing a uniform distribution of fine materials within the grain mass, (b) to measure the *in situ* bulk density of grain placed in a storage bin with and without the aid of a mechanical grain spreader, and (c) to measure the airflow resistance of grain placed in a bin with and without the aid of a mechanical grain spreader.

EQUIPMENT

Grain Bin

Test lots of grain were placed in a 6.4 m (21-ft)-diameter grain bin with 5.5 m (18-ft)-high sidewalls and a 7.0 m (23-ft) peak height. The bin was equipped with a perforated false floor with 14 percent open area made up of 2 mm (5/64-in.)-diameter holes. A mechanical grain bin unloading system was used. A fan with an 11.2 kW (15-hp) variable-speed drive supplied ambient air to the underfloor plenum.

Grain Spreaders

Three mechanical grain spreaders, typical of designs currently or recently in use, were studied. They were: Spreads-All A-3 High Capacity* spreader, Spreads-All E-2 spreader, and NECO Grain Leveler.

The Spreads-All A-3 High Capacity spreader is a spinner type, using a spoked wheel rotating about a vertical shaft as the spreading device. Spreading vanes attached to the underside of the spokes direct the grain outward and downward as the wheel rotates. An assortment of vanes, each with a particular slope, is provided to accommodate a range of bin diameters. The vanes are selected to direct a stream of grain to a particular radius. As a result eight concentric circles of grain are deposited as the bin is filled. A variable-speed drive allows the spreading range to be increased as the bin fills. A funnel is used to deliver the incoming grain to the center of the wheel to reduce the effects of eccentric loading. A flow control device maintains a constant level of material in the funnel. Fig. 1 illustrates this spreader.

The Spreads-All E-2 spreader is

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*Reference to a company or product does not imply approval or recommendation of the product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.

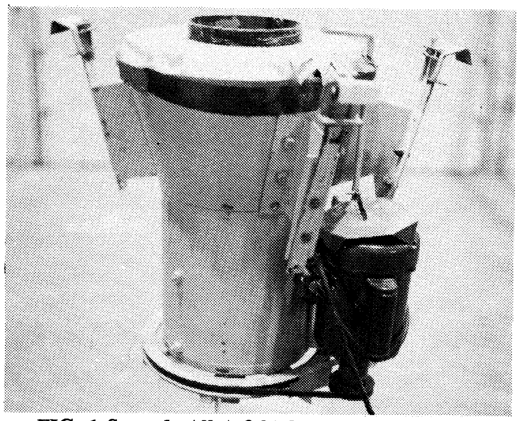

FIG. 1 Spreads-All A-3 high capacity spreader.

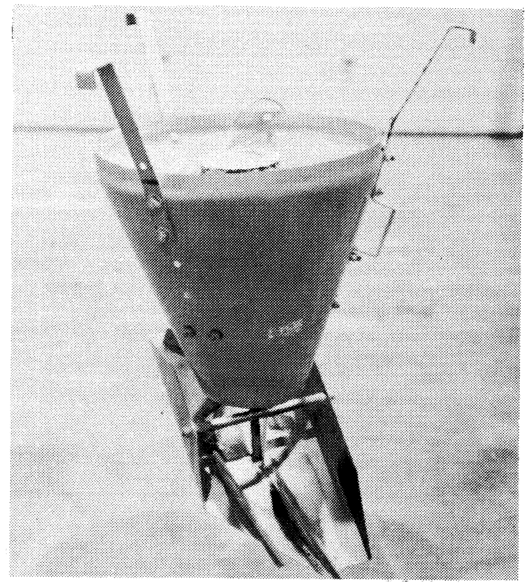

FIG. 2 Speads-All E-2 spreader.

essentially a short section of inclined trough that is rotated about a vertical axis by a reversible electric motor. The ends of the trough are cut off at oblique angles to the long dimension, with the result that different spreading patterns are obtained by reversing the motor. The angle of inclination is adjustable, as is the opening of a small door under the vertical shaft that allows grain to fall to the center of the bin. A funnel that directs the grain stream to the trough (Fig. 2) reduces the effects of eccentric loading.

The NECO Grain Leveler is no longer in production, but its operating principle is sufficiently promising that it was included in this study. The leveler is a revolving horizontal auger, with a perforated outer tube, that is suspended at the center of the bin and rides on a track installed at the bin eave. The tube has nine holes arranged in a helix, covering about one-quarter of the circumference, through which grain is discharged. The tube can be rotated slightly to adjust the distribution. As the auger rotates, a fluted drive roller at its outer end rolls along the track and causes the spreader to revolve around the bin approximately twice each minute. The spreader is illustrated in Fig. 3.

TEST PROCEDURES

The tests reported here were conducted with yellow dent shelled corn that was grown in 1973 and harvested with a corn combine. One portion of the corn had been dried in the field or in a bin by natural air ventilation, and the other portion had been dried with heated air at temperatures of 49-60 C (120-140 F).

Test lots of corn were handled and stored in the headhouse of the US Grain Marketing Research Center. Each lot was initially drawn from a supply bin and thereafter remained a separate, identified lot. Additional grain was added to replace losses from sampling and handling. The usual grain lot size was 32.8 tonnes (1290 bu), which filled the test bin to an average depth of 1.4 m (4.7 ft).

Each test was initiated by weighing the lot on a 380 kg (15-bu) batch scale as it was moved from one holding bin to another. Then the corn was transferred to the test bin at the rate of 45.6 tonnes (1800 bu) per hr. The grain spout consists of 23 cm (9 in.) square steel inclined spouts in the elevator and to the adjoining laboratory, followed by a vertical section of 20 cm (8 in.) round steel spout beginning 15 m (45 ft) above the laboratory floor, ending at the peak of the bin roof. An automatic spout sampler took samples from the grain stream every 90 sec. Consecutive groups of four samples were combined for later analysis of bulk density, moisture content and f.m. content.

A standard compartmented grain probe 3 m (10 ft) long was used to obtain corn samples from the bin along three radial lines at 0.3 m (1-ft) intervals, starting at the bin center. Samples from each two adjacent compartments in the probe were combined and then screened with a 4.8 mm (12/64-in.) round hole sieve. The percentage of each sample that passed through the sieve was recorded, and the results were used to establish a grid that showed the distribution of f.m. in the bin. Average, variance and chi-square values were calculated for all of the samples taken from the three radial lines.

At each location where grain samples were taken the depth of the corn was measured. Each depth was multiplied by the floor area it represented and the products were summed to compute the volume of the grain pile. Since the weight of the grain lot had been previously determined, the average bulk density could then be calculated.

The volume of air that passed through the grain and the pressure required to produce that airflow were recorded to determine the airflow resistance of the corn. A 356 mm (14-in.)-diameter ASME long-radius

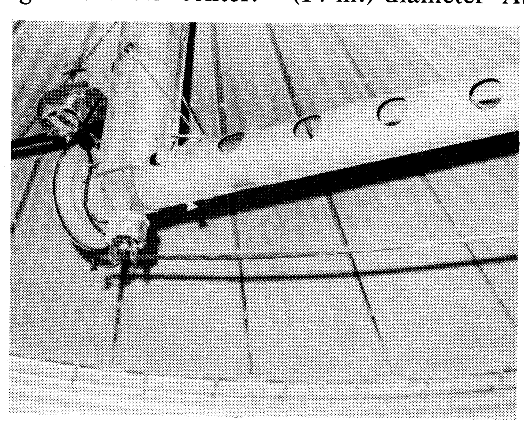

FIG. 3 NECO grain leveler [auger spreader].

TABLE 1. SUMMARY OF TESTS WITH FOUR BIN FILLING METHODS.

Test conditions				Grain conditions* before tests			Test results			
							F.M. distribution			
Test† no.	Spreader used	Corn‡ lot	Filling depth	F.M.	Bulk density	Moisture content	Range‖	Chi-square#	Bulk density	Airflow § resistance
			m	percent	kg/m^3	percent	percent	percent	kg/m^3	Pa/m
1	None	H_1	2.0	5.47	750	12.6	1.7-24.8	2.52	758	—
2	do.	F_1	2.0	3.49	742	11.9	2.2-18.4	4.92	761	—
14	do.	H_2	1.4	2.62	734	13.5	1.9-11.6	5.36	790	128
16	do.	F_2	1.4	3.43	732	14.0	—	—	777	118
17	do.	F_2	2.9	5.11	734	13.8	—	—	743	119
8	Auger	F_2	1.5	4.53	730	14.3	2.9-10.3	0.33	828	233
9	do.	F_2	3.0	3.35	727	14.7	1.5-8.2	0.63	819	218
10	do.	H_2	1.4	1.61	740	13.7	1.2-3.8	0.15	817	198
11	A3	H_2	1.4	2.67	738	13.4	1.7-5.1	0.17	831	247
12	do.	F_2	1.4	3.23	732	14.1	3.0-5.2	0.05	833	288
13	do.	F_2	2.9	3.97	732	14.2	—	—	843	272
20	E2	F_2	1.4	3.92	734	13.5	3.3-6.5	0.20	867	362
21	do.	F_2	2.9	5.09	740	13.9	—	—	875	396

*As determined from samples taken by a spout sampler as corn was moved into test bin.
†Tests with other grains, experimental devices, or with equipment failures are not reported.
‡H=heat-dried corn; F=field or unheated air-dried corn; subscripts=individual lots of corn dried by the respective methods.
§Measured at an airflow rate of 4.6 m^3/min-m^2 (15 cu ft per min-sq ft).
‖Lowest and highest f.m. content obtained from individual probe compartments.
#A statistic representing the variability in f.m.

Unit conversions: 1 lb/ft^3 = 16.02 Kg/m^3; 1 in. of H_2O/ft of grain = 816.4 Pa/m of grain; 1 ft = 0.3048m

flow nozzle, calibrated according to the ASME Power Test Code, was attached to the fan inlet by 2.4 m (8 ft) of 71 cm (28-in)-diameter duct. The nozzle pressure was measured with an inclined manometer.

During the construction of the test bin six static pressure taps were placed under the perforated floor, equally spaced around the bin circumference. The taps were about 5 cm (2 in.) above the solid floor and 25 cm (10 in.) inside the bin wall. A pressure tap was installed in the top of the bin and connected to the low-pressure arm of each manometer so that the pressures recorded were independent of any air exhaust restrictions.

Readings were taken at airflow increments of 0.3 m^3/min-m^2 (1 cu ft per min-sq ft) of floor area over the range of airflows that the fan could deliver, 2-10 m^3/min-m^2 (6-30 cu ft per min-sq ft). The average of the six static pressures was used in subsequent calculations. The difference between the highest and lowest of the six pressures was less than 3 percent of the average pressure.

Because of the nonlinear relationship between airflow and grain depth the following procedure was used to calculate an average grain depth for use in airflow resistance calculations: For each depth measurement, the airflow (m^3/min-m^2) which would have resulted from a static pressure of 747 Pa (3 in. of water) was calculated from Kreyger (1972)(data similar to that reported by Shedd (1953)). This airflow was multiplied by the floor area represented by the depth measurement. The calculation was repeated and the products were summed for all depth measurements. This sum represented the total airflow (m^3/min) through the corn pile at a static pressure of 747 Pa (3 in. of water). This total was divided by the floor area, and the corn depth that would have allowed that specific airflow (m^3/min-m^2) was calculated. Thus, a corn pile of any shape was converted to a pile of uniform depth with the same total airflow. The average static pressure previously determined was then divided by this depth to obtain the specific airflow resistance (Pa/m of grain) at each airflow.

In some tests a second lot of grain was added to the first to determine whether the specific airflow resistance was dependent on the depth of the grain. These tests are indicated by grain depths greater than 2.5 m in Table 1. Bulk density and airflow resistance calculations were repeated after adding the second lot.

After the test data had been recorded, the corn was returned to its original holding bin.

RESULTS

Table 1 lists the results of bin filling tests with shelled corn. F.m. content, bulk density, and moisture content were obtained from samples taken by the automatic spout sampler. The bulk densities listed in Table 1 under grain conditions were determined from spout samples and are included for comparison with the *in situ* bulk densities reported under test results. This comparison provides a measure of the compaction caused by each filling method. Bulk density of the spout samples was established by the grain grading standards test weight technique and then converted from bushel to cubic meter basis.

The tests reported in Table 1 were conducted with dry corn with an initial f.m. content of less than 6 percent. When the corn was placed in the bin from a vertical spout that was centrally located in the bin, the f.m. in the center under the filling spout ranged from 11.6 to 24.8 percent; whereas that near the wall ranged from 1.7 to 2.2 percent. This variability in f.m. content was reflected in the chi-square values of 2.52 to 5.36 percent when no spreader was used.

When the spreaders were used, the f.m. in the center of the bin ranged from 3.8 to 10.3 percent and that near the wall from 1.2 to 3.3 percent. The variabilty in f.m. content, as compared with that when filling without a spreader, is reflected in lower chi-square values, ranging from 0.05 to 0.63 percent. The horizontal distribution of f.m. in selected tests, each typical of a particular filling method, is illustrated in Fig. 4.

Two nonparametric tests, Median and Kruskal-Wallis (Conover 1971), were performed to determine whether there were significant differences between results from the spreaders

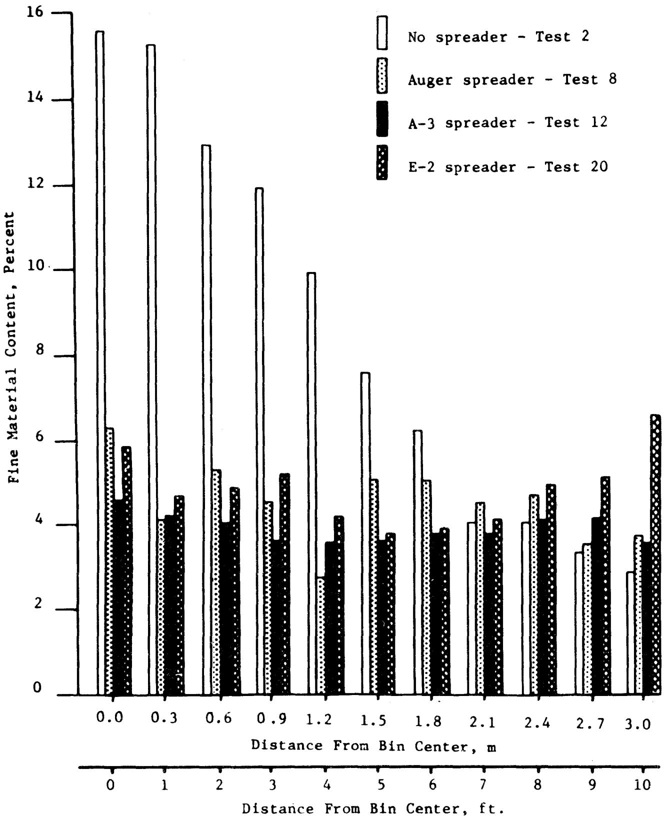

FIG. 4 Horizontal distribution of fine material for tests typical of the four filling methods.

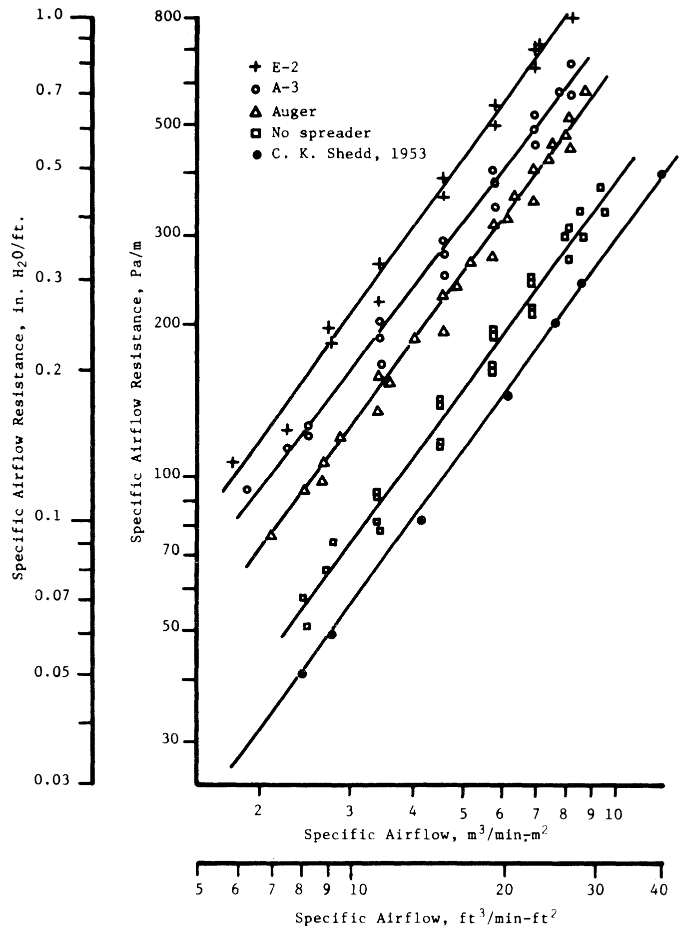

FIG. 5 Specific airflow resistance produced by four filling methods and by loose fill [C. K. Shedd 1953].

and filling methods used, based on the calculated chi-squares and variances. The use of spreaders resulted in a significantly more even distribution of the f.m. inside the storage bin than when no spreader was used. The difference between results from use of the three spreaders was not significant.

The bulk densities measured in the bin were consistently greater than were those measured from samples by the test-weight procedure (Table 1). Filling the bin without a spreader increased the bulk density an average of 3.7 percent. Filling the bin with a spreader produced considerably greater increases in bulk density; an average of 12.5 percent for the auger type, 13.3 percent for the A-3 centrifugal type, and 19.9 percent for the E-2 centrifugal type.

As shown in Table 1, the airflow resistance was also greatly affected by the filling method. Fig. 5 shows the specific airflow resistance versus airflow for all tests with less than 6 percent f.m. as well as that reported by Shedd (1953). The lines are least squares straight-line approximations over the range of airflows encountered in this study. The slopes are not statistically different. At 4.6 m^3/min-m^2 (15 cu ft per min-sq ft) of floor area the bin filled without a spreader had the lowest average resistance, 131 Pa/m (0.161 in H_20 per ft). All of the mechanical spreaders increased the resistance. The auger type produced an average resistance at 4.6 m^3/min-m^2 (15 cu ft per min-sq ft) of 220 Pa/m (0.270 in H_20 per ft); the A-3, 287 Pa/m (0.351 in H_20 per ft); and the E-2 produced 383 Pa/m (0.469 in H_20 per ft).

In the several tests in which a comparison was made, no substantial difference in airflow resistance per foot of depth occurred between results of tests with 32.8 tonnes (1290 bu) of grain (1.5-1.8 m [5-6 ft] depth) and those with 65.7 tonnes (2580 bu) of grain (2.4-3.0 m [8-10 ft] depth) when the filling procedure was the same.

Tests made with no spreader produced cone-shaped piles. Pressure measurements were made both before and after the pile was leveled by hand. The leveling operation increased the measured resistance of the grain lot slightly, but the specific airflow resistance based on the equivalent depth as calculated above was not changed.

Average bulk density and airflow resistance are highly correlated. Fig. 6 shows the regression line of the observations made at 4.6 m^3/min-m^2 (15 cu ft per min-sq ft). The correlation coefficient is +0.93.

Because of the limited supply of corn available for tests and its commitment to other uses, fewer tests were made with some spreaders than with others. In some tests it was impossible to insert the probe to the bottom of the grain pile to obtain a measure of f.m. distribution.

Two additional tests with high-moisture corn produced similar results. One lot with 18.8 percent moisture content had a bulk density of 769 kg/m^3 (48.0 lb per cu ft) and an airflow resistance of 131 Pa/m (0.161 in H_20 per ft) at an airflow of 4.6 m^3/min-m^2 (15 cu ft per min-sq ft) when placed in the bin from a spout. When the same lot was reloaded using the E-2 spreader the bulk density increased to 878 kg/m^3 (54.8 lb per cu ft) and the airflow resistance increased to 281 Pa/m (0.344 in H_20 per ft). A lot with 23.0 percent moisture content had a bulk density of 716 kg/m^3 (44.7 lb per cu ft) and airflow resistance of 117 Pa/m (0.143 in H_20 per ft) when filled from the spout and 819 kg/m^3

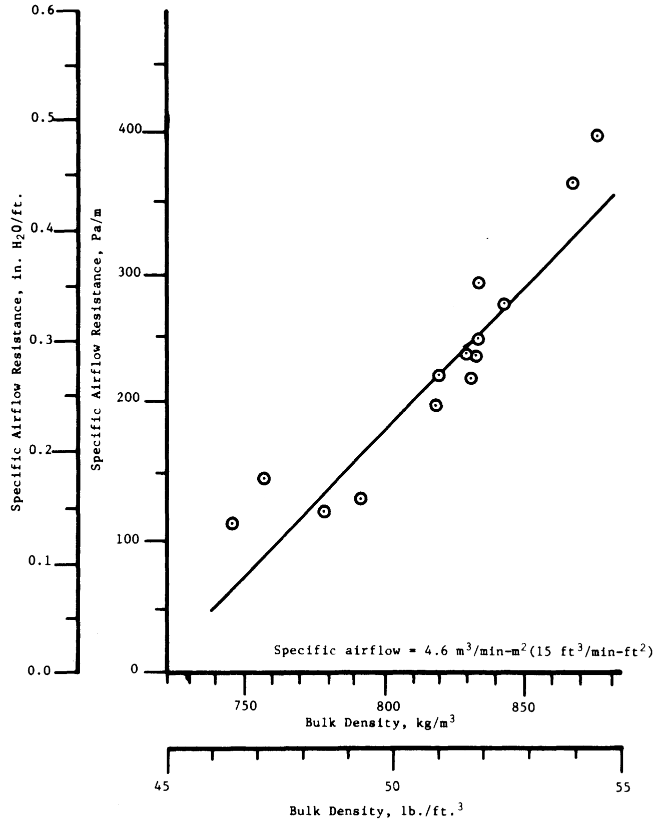

FIG. 6 Specific airflow resistance as affected by bulk density.

(51.1 lb per cu ft) and 231 Pa/m (0.283 in H_2O per ft) when filled with the A-3 spreader.

DISCUSSION OF RESULTS

The observed increase in the bulk density of corn caused by the use of mechanical grain spreaders is a mixed blessing, because the increase in bulk density is accompanied by increased airflow resistance. The reduction in storage cost obtained by storing 9 bu where eight were previously stored may be more than offset by the risk of deterioration from inadequate aeration. If adequate aeration rates are supplied at the increased airflow resistance, the power cost will be increased proportionately.

The results obtained indicate that the data by Shedd (1953) on the resistance of clean shelled corn to airflow should be increased by 20 to 40 percent when designing aeration systems for bins filled without a spreader with corn that contains up to 6 percent f.m. When the mechanical spreaders are used the resistance should be increased by 100 to 300 percent. Similar increases in bulk density and airflow resistance were observed with high-moisture corn.

Both airflow resistance and bulk density appear to be related to the distribution of particles of various sizes within the grain mass. Typically, a mass of whole corn kernels has a void ratio of about 40 percent. Fractions of kernels could be added to the mass of corn by filling the void spaces, thus increasing the bulk density of the mass. By reducing the dimensions of the intergranular spaces the hydraulic radius of the air passages is reduced while their length may be increased, thereby increasing the pressure required to force air through the mass.

Two possible explanations for the increased bulk density of shelled corn in bins filled with mechanical spreaders are offered. It has been widely observed that most granular materials can be compacted by vibrating the container in which they are held. The shower of kernels generated by the grain spreaders produces a similar effect by vibrating the kernels at and immediately below the grain surface. The kernels are moved under the effect of this vibration until they reach a sufficiently stable orientation to prevent further movement. Since the kernels are added to the pile in very thin layers, perhaps a nominal 0.25 mm (0.01 in.) per revolution of the spreader, such compaction can be quite complete, even more so than that which results from vibrating an entire container, such as a rail car. It is also probable that the whole kernels fall to the surface faster than does the f.m., thus allowing the voids between the kernels to be filled after the whole kernels are in place.

Multiple-point filling offers an alternative to excessive airflow resistance and reduces the concentration of f.m. at the center of the bin. Although f.m. will still concentrate under each filling point, each local concentration will be smaller than the one created by single-point filling and hopefully will contain less f.m. A multiple-point filling system will be developed and tested in the future.

It is hoped that the results of this study will permit improved design and operation of aeration systems.

CONCLUSIONS

The following conclusions can be drawn from the results of this research:

1 The use of mechanical grain spreaders to fill a bin with shelled corn significantly improves the uniformity of distribution of fine material within the bulk grain over that obtained when no spreader is used.

2 No significant difference was observed in the uniformity of fine material distribution provided by the mechanical spreaders tested.

3 The use of mechanical grain spreaders significantly increased the bulk density of the grain.

4 The use of mechanical grain spreaders substantially increased the airflow resistance of the bulk grain over that obtained when no spreader was used.

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